



UNIVERSITI PUTRA MALAYSIA

**DESIGN OF AN OPTICAL RECEIVER FOR THE FIBER TO THE
HOME (FTTH) SWITCH**

MOHD HANIF BIN YAACOB

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**DESIGN OF AN OPTICAL RECEIVER FOR THE FIBER TO THE HOME
(FTTH) SWITCH**

By

MOHD HANIF BIN YAACOB

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Partial Fulfillment of the Requirement for the Degree of Master of Science**

August 2002



Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in partial fulfillment of the requirement for the degree of Master of Science

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Chairman: Associate Professor Borhanuddin Mohd Ali, Ph.D.

Faculty: Engineering

Fiber to the home (FTTH) architecture provides the full set optical telecommunication services (narrowband and broadband) up to customer premises across the local access services. The main challenge to the realization of FTTH is the cost. However, as the installation cost of the optical fiber technology decreases, FTTH started to gain its reputation as the future communication infrastructure. Once implemented, FTTH architecture needs to maintain its reliability and connectivity. These responsibilities are given to FTTH switch; a network device in the FTTH network that provides very fast inter-connectivity and excellent backup features. One main component of the switch is the optical receiver to receive the optical signal from any locations, either from the central office or the premises and convert the signal to its electrical form to be processed by the switch. Therefore, the objective of the research is to design the optical receiver for the FTTH switch.

In this thesis, the intended bandwidth by the receiver is specified at 155 MHz. The other performance parameters concerned are signal to noise ratio (SNR) and sensitivity. The main components of the receiver are PIN photodetector, transimpedance



amplifier and post amplifier. PIN photodetector is used as the optical detector to convert the optical signal into its electrical form. Meanwhile, transimpedance amplifier is the photocurrent to voltage converter. The function of the post amplifier is to amplify the electrical signal. Besides that, additional circuit configuration and topology are applied to improve the performance of the receiver.

The optical receiver design was broken into a few modules. Each of them was developed step by step based on two approaches. They are software simulation and hardware implementation (experiment). The receiver performance was analysed based on the results produced by each approach.

The final results on the optical receiver system show that the performance standard (155 MHz bandwidth) was achieved by the simulation approach. However the experiment only manage to support the bandwidth around 126 MHz. The SNR and sensitivity measured from the experimental circuit also give a lower performance compared to the simulation.

Based on the experimental results, a few solutions are suggested to increase the optical receiver performance. Meanwhile, the application of the designed optical receiver in the other area is also investigated.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

**REKABENTUK PENERIMA OPTIK UNTUK SUIS “FIBER KE RUMAH”
(FTTH)**

Oleh

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Senibina fiber ke rumah (FTTH) menyediakan satu set lengkap perkhidmatan telekomunikasi optik (jalur sempit dan jalur luas) sehingga ke premis pelanggan melalui perkhidmatan capaian tempatan. Cabaran utama untuk menjalankan FTTH ialah kos. Walau bagaimanapun, disebabkan kos prasarana teknologi fiber optik semakin menurun, FTTH mulai mendapat tempat sebagai infrastruktur komunikasi masa hadapan. Apabila diimplementasi, senibina FTTH perlu mempertahankan kebolehpercayaan dan kesalinghubungannya. Tugas-tugas ini diserahkan kepada suis FTTH; satu peranti rangkaian di dalam rangkaian FTTH yang menyediakan kesalinghubungan yang pantas dan ciri sandaran yang cemerlang. Salah satu komponen suis ini ialah penerima optik yang menerima isyarat optik dari mana-mana lokasi, tidak kira dari pejabat pusat atau premis dan menukarkan isyarat optik tersebut kepada bentuk elektrik untuk diproses oleh suis. Oleh itu, objektif penyelidikan ini adalah untuk merekabentuk satu penerima optik untuk suis FTTH.

Di dalam tesis ini, lebar jalur yang diinginkan oleh penerima optik ditetapkan pada 155 MHz. Parameter prestasi lain yang diambil berat adalah nisbah isyarat ke

hingar (SNR) dan kepekaan. Komponen utama penerima adalah pengesan cahaya PIN, penguat antara-galangan dan penguat pasca. Pengesan cahaya PIN digunakan sebagai pengesan optik untuk menukarkan isyarat optik kepada bentuk elektrik. Sementara, penguat antara-galangan ialah penukar arus cahaya kepada volt. Fungsi penguat pasca pula adalah untuk menguatkan isyarat elektrik tersebut. Selain itu, konfigurasi litar dan topologi tambahan juga digunakan untuk meningkatkan prestasi penerima.

Rekabentuk penerima optik dipecahkan kepada beberapa modul. Setiap satu daripadanya dimajukan langkah demi langkah berdasarkan dua pendekatan. Pendekatan tersebut adalah simulasi perisian dan implementasi perkakasan (eksperimen). Prestasi penerima dianalisa berdasarkan keputusan yang dihasilkan oleh setiap pendekatan.

Keputusan akhir sistem penerima optik menunjukkan piawaian prestasi (lebarjalur 155 MHz) telah dicapai oleh pendekatan simulasi. Walau bagaimanapun, eksperimen hanya mampu menyokong lebarjalur sekitar 126 MHz. SNR dan kepekaan yang diukur dari litar eksperimen juga menunjukkan prestasi yang lemah berbanding simulasi.

Berdasarkan keputusan eksperimen, beberapa penyelesaian dicadangkan untuk meningkatkan prestasi penerima optik. Pada masa yang sama, aplikasi penerima optik yang dicipta di dalam bidang lain juga diteroka.

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I certify that an Examination Committee met on 5th August 2002 to conduct the final examination of Mohd Hanif bin Yaacob on his Master of Science thesis entitled "Design of an Optical Receiver for the Fiber to the Home (FTTH) Switch" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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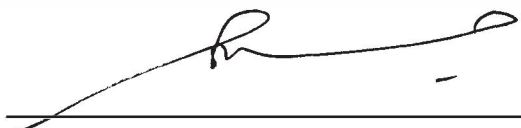
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DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



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TABLE OF CONTENTS

	Page
ABSTRACT	ii
ABSTRAK	iv
ACKNOWLEDGEMENTS	vi
APPROVAL SHEETS	vii
DECLARATION	ix
LIST OF TABLES	xiii
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xix
LIST OF NOTATIONS	xxi

CHAPTERS

1.0 INTRODUCTION	1
1.1 Future Media in Telecommunication Network	1
1.2 The Optical Receiver	3
1.3 Problem Statement	4
1.4 Objectives	5
1.5 Related Product Review	6
1.6 Methodology	8
1.7 Thesis Organization	9
2.0 DESIGN CONSIDERATIONS	11
2.1 The Receiver Section	12
2.1.1 Photodetector	14
2.1.1.1 Typical Photodetector Specifications	15
2.1.1.2 Types of Photodetectors	18
2.1.2 The Amplifier Circuit	21
2.1.2.1 Low Impedance Amplifier	22
2.1.2.2 High Impedance Amplifier	23
2.1.2.3 Transimpedance Amplifier	24
2.1.2.4 The Justification of Transimpedance Amplifier as a Current to Voltage Converter	28
2.1.2.5 The Post Amplifier	30
2.1.3 The Demodulation Circuit	31
2.2 Noise Consideration	32
2.2.1 Photodetector Noise	32
2.2.2 Amplifier Noise	33
2.2.3 Noise Equivalent Power (NEP)	34
2.2.4 Noise Equivalent Bandwidth (NEB)	35
2.3 Conclusion	36
3.0 DESIGN AND TEST APPROACHES	38
3.1 System Study	38
3.1.1 Optical Fiber Communication Required Specifications for Receiver	38



3.1.2 Design Parameters	39
3.1.3 Performance Parameters	40
3.2 Design and Simulation Software	42
3.2.1 Electronic Workbench 5.0 Overview	43
3.2.2 The Justification of AC Current Source to Simulate the Photodetector Current	44
3.3 Laboratory Experiment Setup	46
3.3.1 Test and Measurement Instruments	47
3.3.2 Experimental Setup	48
3.4 Conclusion	51
 4.0 OPTICAL RECEIVER DEVELOPMENT AND RESULTS	 52
4.1 Receiver with Transimpedance Amplifier	52
4.1.1 Simulation Result	57
4.1.1.1 Gain	58
4.1.1.2 Frequency Response	59
4.1.1.3 Sensitivity	60
4.1.1.4 Output Waveform	62
4.1.2 Experimental Result	64
4.1.2.1 Gain	64
4.1.2.2 Frequency Response	65
4.1.2.3 Sensitivity	65
4.1.2.4 Output Waveform	67
4.1.2.5 Noise	68
4.2 The Insertion of Feedback Capacitors	69
4.2.1 Simulation Result	72
4.2.1.1 Gain	72
4.2.1.2 Frequency Response	73
4.2.1.3 Sensitivity	74
4.2.1.4 Output Waveform	76
4.2.2 Experimental Result	77
4.2.2.1 Gain	77
4.2.2.2 Frequency Response	78
4.2.2.3 Sensitivity	78
4.2.2.4 Output Waveform	80
4.2.2.5 Noise	82
4.3 The Introduction of Post Amplifier	82
4.3.1 Simulation Result	84
4.3.1.1 Gain with Post Amplifier	84
4.3.1.2 Frequency Response with Post Amplifier	85
4.3.1.3 Sensitivity with Post Amplifier	86
4.3.1.4 Output Waveform with Post Amplifier	88
4.3.2 Experimental Result	89
4.3.2.1 Gain with Post Amplifier	89
4.3.2.2 Frequency Response with Post Amplifier (Signal Generator)	90
4.3.2.3 Sensitivity with Post Amplifier	91
4.3.2.4 Output Waveform with Post Amplifier	93
4.3.2.5 Noise with Post Amplifier	95
4.3.2.6 Signal-To-Noise Ratio (SNR)	99
4.3.2.7 Noise Equivalent Power (NEP)	101

4.4 The Multistage Amplifier Analysis – Simple Miller Compensation Topology	102
4.4.1 Simulation Result	104
4.4.1.1 Gain with Miller Compensation Post Amplifier Circuit	104
4.4.1.2 Frequency Response with Miller Compensation Post Amplifier Circuit	105
4.4.1.3 Sensitivity with Miller Compensation Post Amplifier Circuit	106
4.4.1.4 Output Waveform with Miller Compensation Post Amplifier Circuit	108
4.4.2 Experimental Result	109
4.4.2.1 Gain with Miller Compensation Post Amplifier Circuit	109
4.4.2.2 Frequency Response with Miller Compensation Post Amplifier Circuit	110
4.4.2.3 Sensitivity with Miller Compensation Post Amplifier Circuit	111
4.4.2.4 Output Waveform with Miller Compensation Post Amplifier Circuit	113
4.4.2.5 Noise	115
4.4.2.6 Signal-To-Noise Ratio (SNR)	117
4.4.2.7 Noise Equivalent Power (NEP)	118
4.5 Conclusion	119
 5.0 CONCLUSION AND FUTURE WORK	 120
5.1 Conclusion	120
5.2 Future Work	122
 REFERENCES	 124
 APPENDICES	 128
Appendix A Components Datasheets	128
Appendix B Result Tables for Optical Receiver with Transimpedance Amplifier Circuit	133
Appendix C Result Tables for Optical Receiver with Feedback Capacitor Circuit	136
Appendix D Result Tables for Optical Receiver with Post Amplifier Circuit	140
Appendix E Result Tables for Optical Receiver with Miller Compensation Post Amplifier Circuit	144
 BIODATA OF THE AUTHOR	 149

LIST OF TABLES

Table		Page
1.1	Technical specifications for optical receiver of TC3200 Media Converter	7
B.1	Transimpedance Amplifier: Simulated gain versus bandwidth	133
B.2	Transimpedance Amplifier: Simulated output voltage versus optical input power (155 MHz bandwidth)	134
B.3	Transimpedance Amplifier: Simulated output voltage versus optical input power (300 kHz bandwidth)	134
B.4	Transimpedance Amplifier: Experimental gain versus bandwidth	135
B.5	Transimpedance Amplifier: Experimental output voltage versus optical input power (300 kHz bandwidth)	135
C.1	With Feedback Capacitor: Simulated gain versus bandwidth	136
C.2	With Feedback Capacitor: Simulated output voltage versus optical input power (155 MHz bandwidth)	137
C.3	With Feedback Capacitor: Simulated output voltage versus optical input power (300 kHz bandwidth)	138
C.4	With Feedback Capacitor: Experimental gain versus bandwidth	138
C.5	With Feedback Capacitor: Experimental output voltage versus optical input power (300 kHz bandwidth)	139
D.1	With Post Amplifier: Simulated gain versus bandwidth	140
D.2	With Post Amplifier: Simulated output voltage versus optical input power (155 MHz bandwidth)	140
D.3	With Post Amplifier: Simulated output voltage versus optical input power (300 kHz bandwidth)	141
D.4	With Post Amplifier: Experimental gain versus bandwidth using optical source	141
D.5	With Post Amplifier: Experimental gain versus bandwidth using signal generator	142
D.6	With Post Amplifier: Experimental output voltage versus optical input power (300 kHz bandwidth)	142



D.7	With Post Amplifier: Experimental output voltage versus optical input power (155 MHz bandwidth)	143
E.1	With Miller Compensation: Simulated gain versus bandwidth	144
E.2	With Miller Compensation: Simulated output voltage versus optical input power (155 MHz bandwidth)	145
E.3	With Miller Compensation: Simulated output voltage versus optical input power (300 kHz bandwidth)	146
E.4	With Miller Compensation: Experimental gain versus bandwidth using optical source	146
E.5	With Miller Compensation: Experimental gain versus bandwidth using signal generator	147
E.6	With Miller Compensation: Experimental output voltage versus optical input power (300 kHz bandwidth)	147
E.7	With Miller Compensation: Experimental output voltage versus optical input power (155 MHz bandwidth)	148

LIST OF FIGURES

Figure		Page
1.1	The location of FTTH switch in FTTH system	5
2.1	The equivalent circuit for the optical receiver	12
2.2	Low impedance front-end optical receiver	22
2.3	High impedance front-end optical receiver with equalizer	23
2.4	Transimpedance front-end optical receiver	24
2.5	Equivalent Circuit for photodetector and transimpedance amplifier	25
2.6	Current to voltage conversion using resistor R_1	28
2.7	Current to voltage conversion using transimpedance amplifier	29
2.8	Demodulation block diagram for OOK modulation	31
2.9	Noise Equivalent Bandwidth (NEB) for low pass transfer function	36
3.1	Electronic Workbench graphic interface	43
3.2	AC current source properties	45
3.3	Frequency response determination laboratory setup	48
3.4	Sensitivity determination laboratory setup	49
4.1	2 GHz GBWP transimpedance op amp circuit	54
4.2	Simulation model of 2 GHz GBWP transimpedance op amp circuit	56
4.3	Simulated gain versus bandwidth	58
4.4	The determination of simulated -3 dB bandwidth	59
4.5	Simulated frequency output voltage versus optical input power	60
4.6	Simulated bandwidth versus optical input power to show the frequency response stability	61
4.7	Figure 4.7: Trace for a) 1 kHz output signal b) 100 MHz output signal	62
4.8	Waveforms at 155 MHz a) 0 dBm output signal b) -8 dBm output signal	63
4.9	Experimental gain versus bandwidth	64



4.10	Experimental output voltage versus optical input power	65
4.11	Experimental bandwidth versus optical input power	66
4.12	Trace for a) 1 kHz output signal b) 300 kHz output signal	67
4.13	Trace for a) -2 dBm output signal b) -15 dBm output signal	68
4.14	Circuit model for parasitic input capacitances analysis	70
4.15	Simulated gain versus bandwidth for feedback capacitor circuit	72
4.16	The determination of simulated -3 dB bandwidth for feedback capacitor circuit	73
4.17	Simulated output voltage versus optical input power for feedback capacitor circuit	74
4.18	Simulated bandwidth versus optical input power for feedback capacitor circuit	75
4.19	Trace for a) Output voltage at 160 MHz without C_f b) Output voltage at 160 MHz with the introduction of C_f	76
4.20	Experimental gain versus bandwidth for feedback capacitor circuit	77
4.21	Experimental output voltage versus optical input power for feedback capacitor circuit	78
4.22	Experimental bandwidth versus optical input power for feedback capacitor circuit	79
4.23	Experimental results at a) 1 kHz output signal b) 300 kHz output signal	80
4.24	Experimental result at a) -5.24 dBm output signal b) -25.24 dBm output signal	81
4.25	Optical receiver circuit with post amplifier	82
4.26	Simulated gain versus bandwidth for post amplifier circuit	84
4.27	The determination of simulated -3 dB bandwidth for post amplifier circuit	85
4.28	Simulated output voltage versus optical input power for post amplifier circuit	86
4.29	Simulated bandwidth versus optical input power for post amplifier circuit	87

4.30	Simulated output waveforms for post amplifier circuit a) At 155 MHz b) At 300 kHz	88
4.31	Experimental gain versus bandwidth for post amplifier circuit	89
4.32	The determination of experimental -3 dB bandwidth for post amplifier circuit	90
4.33	Experimental output voltage versus optical input power for post amplifier circuit	91
4.34	Experimental bandwidth stability versus optical input power for post amplifier circuit	92
4.35	Post amplifier output signals a) 300 kHz signal at 0 dBm input power b) Signal at -32 dBm input power	93
4.36	Post amplifier signals a) Signal at 0 dBm input power b) Signals at -14 dBm input power	94
4.37	Post amplifier with simple Miller compensation topology	103
4.38	Simulated gain versus bandwidth for Miller compensation post amplifier circuit	104
4.39	The determination of simulated -3 dB bandwidth for Miller compensation post amplifier circuit	105
4.40	Simulated output voltage versus optical input power for Miller compensation post amplifier circuit	106
4.41	Simulated bandwidth versus optical input power for Miller compensation post amplifier circuit	107
4.42	Simulated output waveforms for Miller compensation post amplifier circuit a) At 155 MHz b) At 300 kHz	108
4.43	Experimental gain versus bandwidth For Miller compensation post amplifier circuit	109
4.44	The determination of experimental -3 dB bandwidth for Miller compensation post amplifier circuit	110
4.45	Experimental output voltage versus optical input power for Miller compensation post amplifier circuit	111
4.46	Experimental bandwidth stability versus optical input power for Miller compensation post amplifier circuit	112
4.47	Miller Compensation Post Amplifier Output Signal a) 300 kHz signal at -5 dBm input power b) At -50.24 dBm input power	113

4.48	Miller compensation post amplifier signals a) Signal at 0 dBm input power b) Signals at -12 dBm input power	114
A.1	Datasheet (Photodetector specifications)	128
A.2	Datasheet (Photodetector characteristics)	129
A.3	Datasheet (Amplifier descriptions)	130
A.4	Datasheet (Amplifier open loop characteristics)	131
A.5	Datasheet (Amplifier closed loop characteristics)	132



LIST OF ABBREVIATIONS

AC	-	Alternating Current
APD	-	Avalanche Photodiode
ATM	-	Asynchronous Transfer Mode
BNC	-	Bayonet Neil-Concelman/British Naval Connector
DC	-	Direct Current
EMI	-	Electromagnetic Interference
ESD	-	Electrostatic Discharge
FDDI	-	Fiber Distributed Data Interface
FTTH	-	Fiber To The Home
GBWP	-	Gain Bandwidth Product
LSBW	-	Large Signal Bandwidth
NEB	-	Noise Equivalent Bandwidth
NEP	-	Noise Equivalent Power
OLT	-	Optical Line Termination
ONU	-	Optical Network Unit
OOK	-	On-Off Keying
Op amp	-	Operational Amplifier
PBX	-	Private Branch Exchange
PCB	-	Printed Circuit Board
PD	-	Photodiode
PIN	-	p - n junction with intrinsic region, i
PN	-	p - n junction
POTS	-	Plain Old Telephone Service
RJ11	-	Registered Jack 11



RJ45	- Registered Jack 45
SMC	- Simple Miller Compensation
SNR	- Signal to Noise Ratio
STM-1	- Synchronous Transfer Mode 1

LIST OF NOTATIONS

η	- Quantum Efficiency
ω	- Operating Frequency (Radian)
λ	- Operating Wavelength
A_v	- Voltage Gain
B	- Bandwidth
B_n	- Noise Bandwidth
C_a	- Amplifier Capacitance
C_d	- Detector Capacitance
C_D	- Detector Capacitance
C_{EL2075}	- Elantec Amplifier Capacitance
C_f	- Feedback Capacitor
$C_{in(CM)}$	- Common Mode Input Capacitance
$C_{in(Diff)}$	- Differential Input Capacitance
C_T	- Total Capacitance
e	- Electronic Charge (1.6×10^{-19})
f	- Varied Input Frequency
G	- Open Loop Gain
h	Planck's Constant (6.626×10^{-34})
H_{CL}	- Closed Loop Transfer Function
i_a	- Total Amplifier Noise
i_{amp}	- Amplifier Input Leakage Current
I_d	- Dark Current
i_D	- Dark Current Noise
i_{det}	- Photodetector Current



i_f	-	Feedback Current
i_n	-	Total Noise
I_p	-	Output Photocurrent
i_s	-	Shot/Quantum Noise
i_t	-	Thermal Noise
K	-	Boltzmann's Constant
P_{ES}	-	Electrical Output Signal Power
P_N	-	Total Noise Power
P_o	-	Incident Optical Power
Q factor	-	Quality Factor
R	-	Responsivity
R_0	-	Output Resistance
R_a	-	Amplifier Input Resistance
R_b	-	Detector Bias Load
R_f		Feedback Resistor
R_L	-	Load Resistor
R_M	-	Nulling Resistor
R_T	-	Total Resistance
R_{TL}	-	Total Parallel Resistances (Bias And Amplifier Resistances)
T	-	Absolute Temperature
v		Velocity of light ($2.998 \times 10^8 \text{ ms}^{-1}$)
V_{amp}	-	Amplifier Input Noise Voltage
V_{bias}	-	Bias Input Voltage
V_{in}	-	Input Voltage
V_{out}	-	Output Voltage
V_p	-	Peak Output Voltage

V_{p-p}	-	Peak-To-Peak Output Voltage
V_{rms}	-	Root Mean Square Output Voltage
Z	-	Impedance
Z_c	-	Capacitor Impedance

CHAPTER 1

INTRODUCTION

In this chapter, the background of fiber optics communications are given to provide the motivation that leads to the research area. It also provides the overview of the research area and its accomplishment.

1.1 Future Media in Telecommunication Network

The period of 21st century promise a further shift in the telecommunication technology from the conventional electrical copper-based system to the increasingly popular optical fiber-based system. An important breakthrough in the making of the commercialised fiber optic cable by the scientists at Corning Glass Work in 1970 had lead to an optimistic future of optical fiber telecommunication system (Hecht, 1999). Since then, optical fibers gained its popularity and started to be used widely by the telecommunication companies especially as the backbone for the intercity communication network. The Internet had pushed further the popularity of the optical telecommunication. The explosive growth of the Internet has had a dramatic impact on the communication network. The popularity of networking together with the increase in demand for multimedia over the Internet are forcing the network to deliver more bandwidth to the users with more reliable and secure connections. The bandwidth will always be a scarce resource in the future, as new services will emerge and more and more people shift from using traditional communication equipment to Internetworking facilities (Rantanen, 1998). Optical fiber technology is without doubt the media that can fulfil all the demands.